Implementing Advanced Grid Codes

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Why do we Need Advanced Grid Codes?

"European Blackout", Nov. 2006

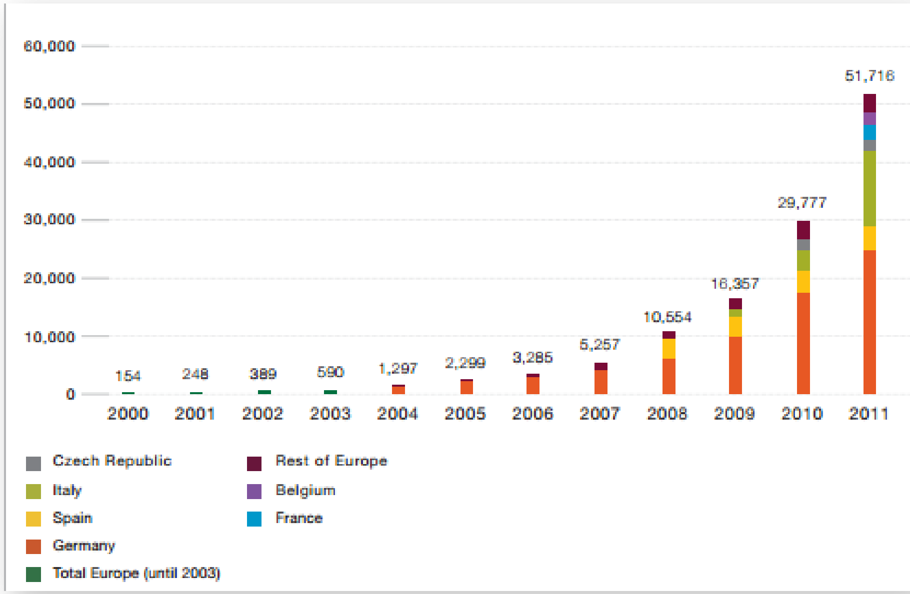
- German electric power Transmission System Operator (TSO) disconnected an extra-high voltage line to allow passage of the "Norwegian Pearl" to the North Sea
  - 380 kV double circuit switched off
  - Other lines on the network near maximum capacity
  - A connection line between two TSO systems overloads
  - Line automatically shuts down as protection

  - 14 seconds – overload cascades throughout Germany
  - Next 5 seconds – cascades throughout Europe, network synchronization is lost, reaches Morocco, Algeria and Tunisia
  - Electricity supply is interrupted in 20 European countries

Capacity of Renewable Energies Increases Dramatically

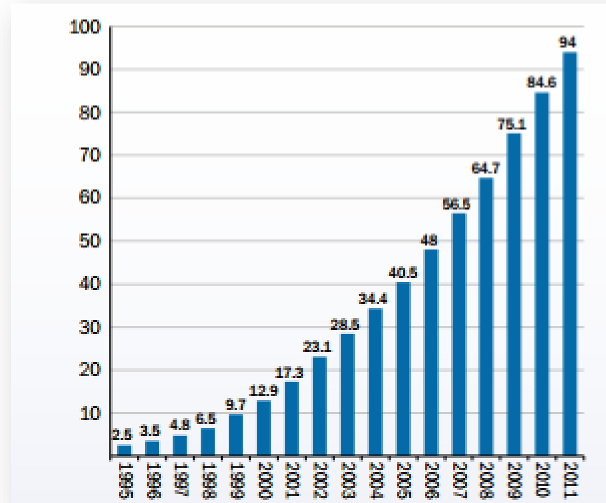
Cumulative photovoltaic capacity, Europe 2000-2011

52GW

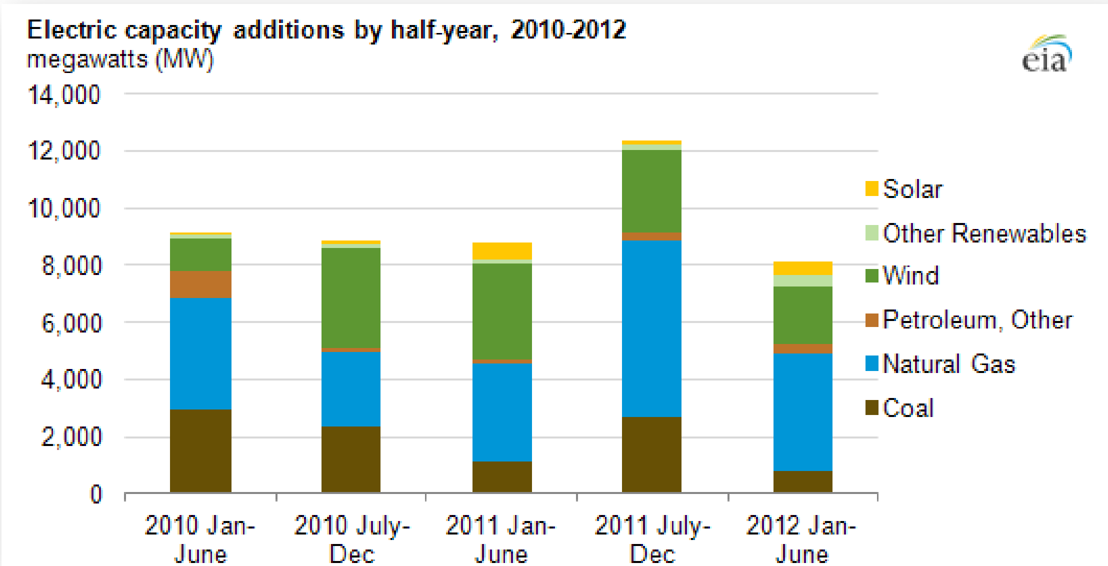


Cumulative wind power capacity, Europe 1995-2011

94GW



Renewables Play Major Role in Electric Capacity Additions

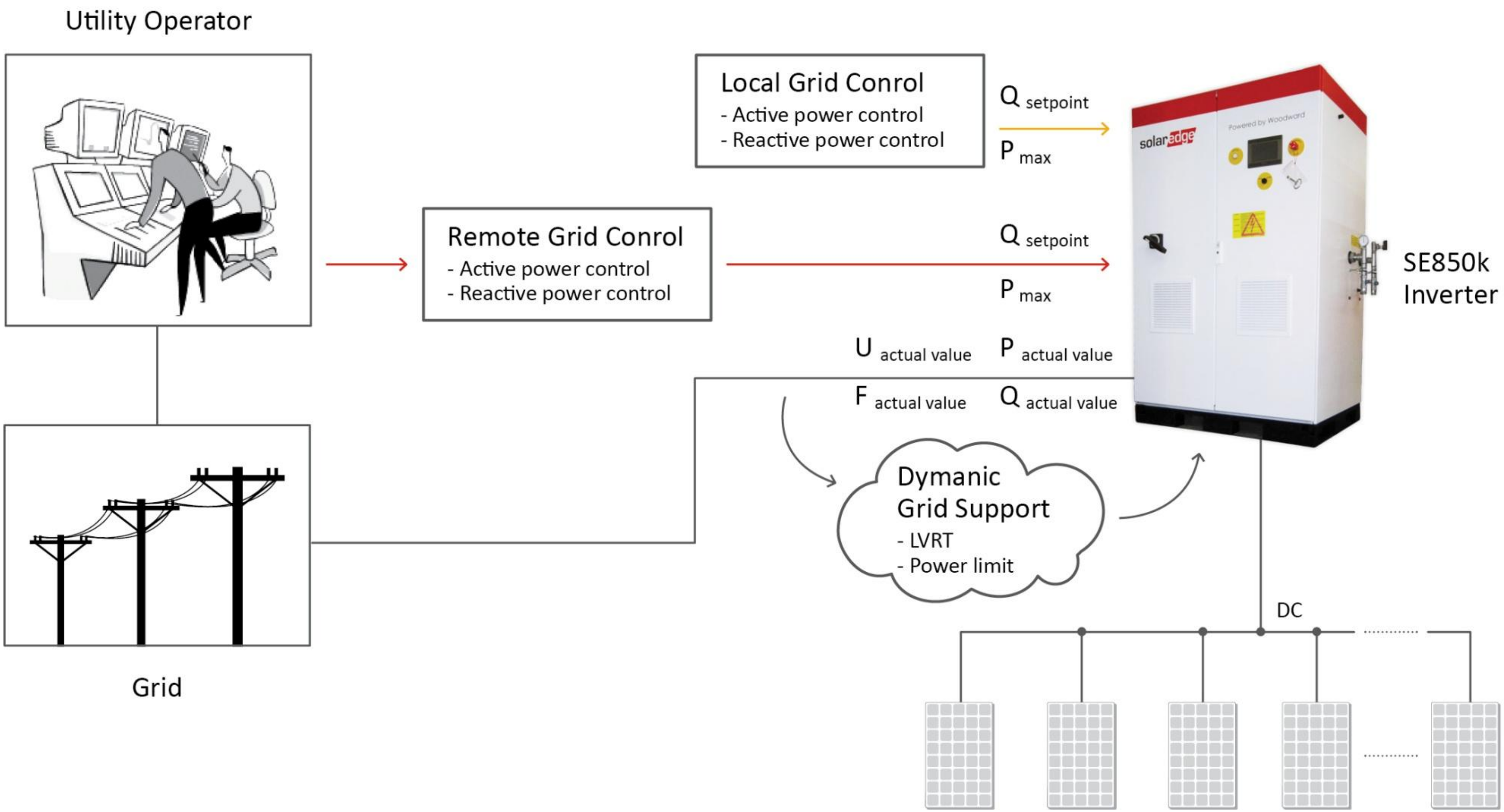


- Until recently – all inverters disconnect when grid is unstable… Hundreds of GW cannot just disconnect…
- PV and wind power sources had to "mature" and behave like other power sources

Overview

Medium Voltage Grid Control

- Illustration of grid control strategies for PV plants



Advanced Grid Control - General

- Strategies for advanced grid control can be divided into 3 categories:
  - **Active power control** – prevent overload of the lines & maintain stable grid
  - **Reactive power control** – maintain stable grid
  - **Low voltage ride through (LVRT)** – prevent immediate grid failure following grid instability
- Active and reactive power control strategies can be:
  - Permanent or dynamic
  - Local or remote

Active Power Control – Examples

Active Power Control

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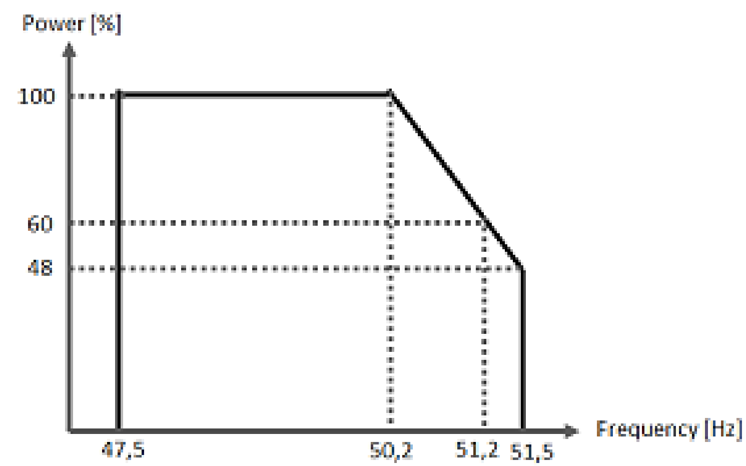
- Target: avoid overproduction, prevent overload of the lines & maintain stable grid
- Six methods for limiting the active power of an installation:
  1. Reduction of active power depending on grid frequency
  2. Inverter output power limitation:
     - On demand (remote) or constant (local)
  3. Gradual power decrease when DC power drops
  4. Gradual power increase after inverter fault or reset
  5. Phase balancing
  6. Limited grid frequency range for inverter wakeup
- One or all methods can be employed simultaneously

1. Frequency-Based Power De-rating

- Inverter power de-rates when grid frequency changes, according to a pre-defined graph [P(f)]
- Inverter disconnects when frequency reaches the trip value

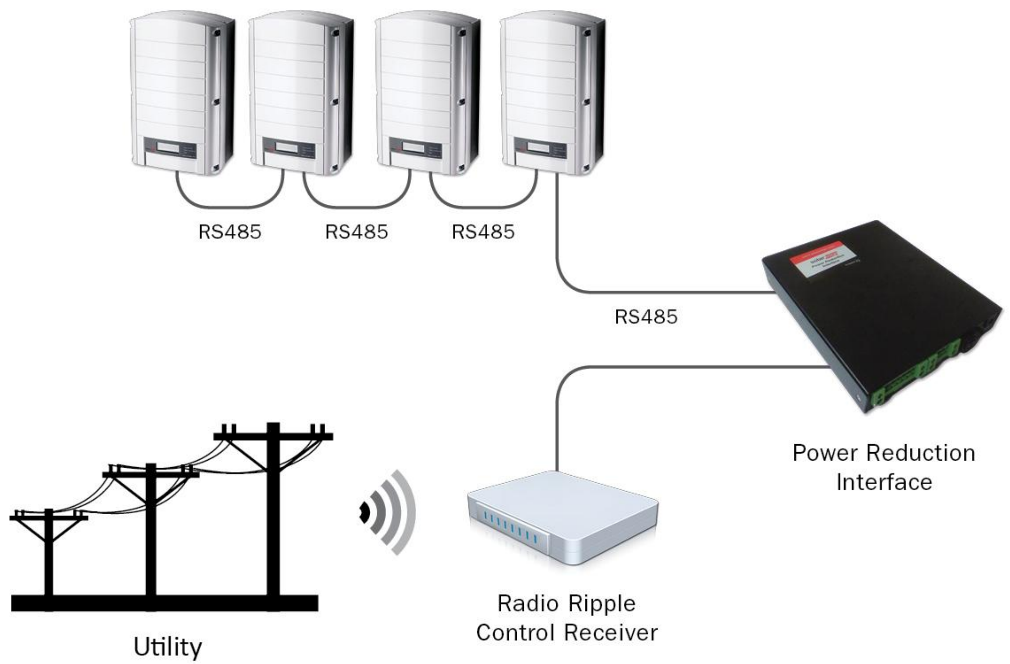
Typical [P(f)] graph



- Controlled by inverter
- Employed in Germany, Italy, Belgium and Slovenia

2a. Remote Output Power Limitation

- Inverter is connected to an interface that receives commands from the grid operator and reduces power accordingly
- Controlled remotely
- Utilized in Germany in all systems >30kVA (limitation to 100%, 60%, 30%, 0% of maximum inverter power)



2b. Local Output Power Limitation

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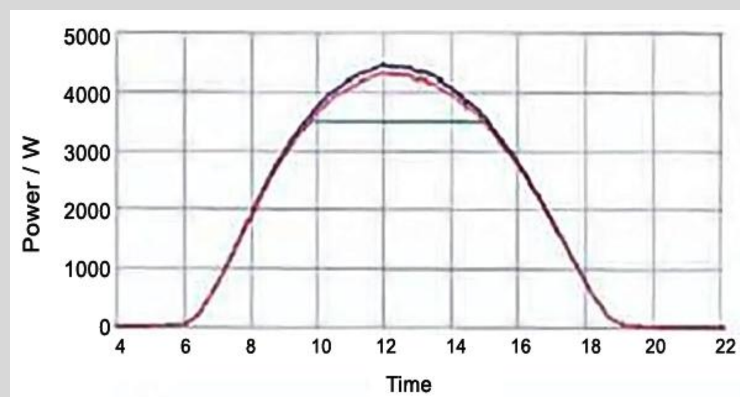
- Inverter is set to a maximum power lower than its rated power
- Utilized in Germany for installations <30kVA without remote control. Ratio between AC power fed into grid and DC(STC) power must be 70%
- Example – 70% ratio in a 10kWp system:
  1. Use a 7kVA inverter
  2. Use a larger inverter and limit its maximum power to 7kVA
  3. Design module layout so that system will not produce more than 7kVA at any given moment. For example – modules on east and west facets

- *Tests* show that when using methods 1 or 2, the actual energy loss is about 6%, and not 30%, since a system usually produces less than its STC*
- *When using method 3 no energy is lost*

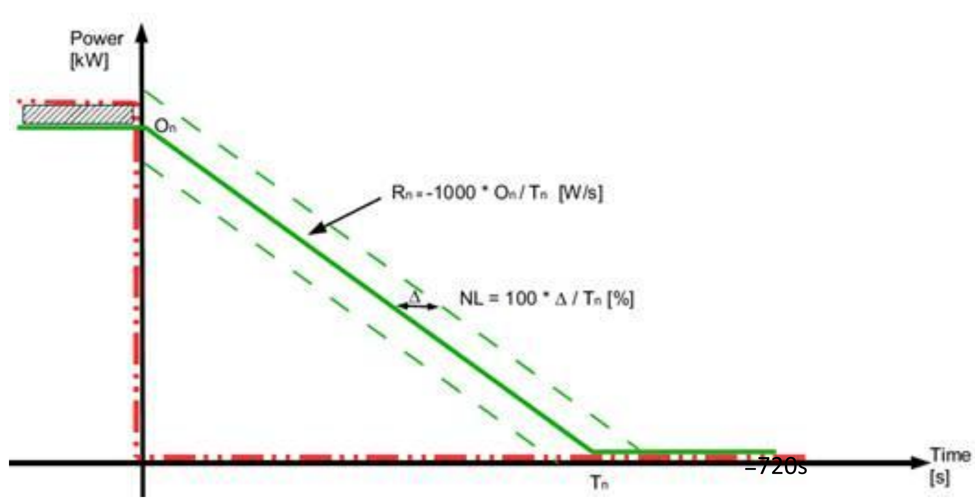
* Based on measurements in Freiburg by Fraunhofer



3. Gradual Power Output Decrease

- Output power in case of drop in DC power must not decrease faster than a pre-defined ramp-down rate
- Utilized in Western Australia
- Inverter must have energy storage capability, to guarantee available power for the ramp down phase
- inverter cannot start before battery stores enough energy to maintain the ramp down phase

Typical graph:



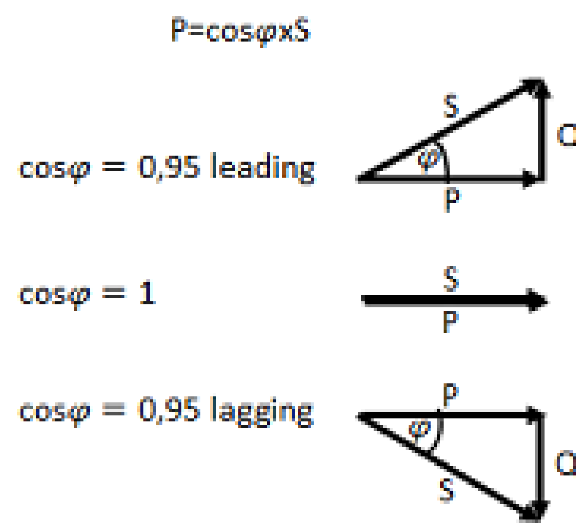
Additional Methods

4. Gradual power increase – after a fault or inverter reset, inverter begins power production gradually. A typical gradient is an increase of 10% of nominal power per minute
   - Controlled by inverter
   - Utilized in Germany, Italy, Belgium and Slovenia
5. Phase balancing – limited maximum permitted power difference between the 3 phases, in systems connected to a three phase grid using single phase inverters (typically 4.6-5kVA)
   - Utilized in Germany, Italy, Belgium, Israel, North America and more
6. Limited grid frequency range - inverter operates in a certain grid frequency or voltage range but will start production only in a range narrower than the operating range
   - Controlled by inverter
   - Utilized in Germany, Italy and Belgium

Reactive Power Control – Examples

Terminology

- **P** – Active power (fed to the grid), measured in W
- **Q** – Reactive power (lost on induction and capacitance), measured in VAR
- **S** – Apparent power (vectorial sum of P and Q, I*V), measured in VA
- **Cosφ** – the cosine of the angle (φ) between S and P (the phase lag between I and V); often used to define the required Q (given the inverter's S and Cosφ, Q can be determined)
- The following relations exist:
  - $P^2+Q^2=S^2$
  - $P=\cos\varphi * S$



Reactive Power Control – 1/2

- Target: maintain stable grid
- Five methods for limiting the reactive power of an installation are used. Only one method can be used at a time
  1. Cosφ – a constant Cosφ
     - Locally set – utilized in Germany, Italy , Slovenia
     - Remotely controlled – in Germany, Italy
  2. Cosφ(P) – Cosφ changes with P, according to a pre-defined graph
     - Locally set
     - Utilized in Germany, Italy and Slovenia
     - Typical graph:

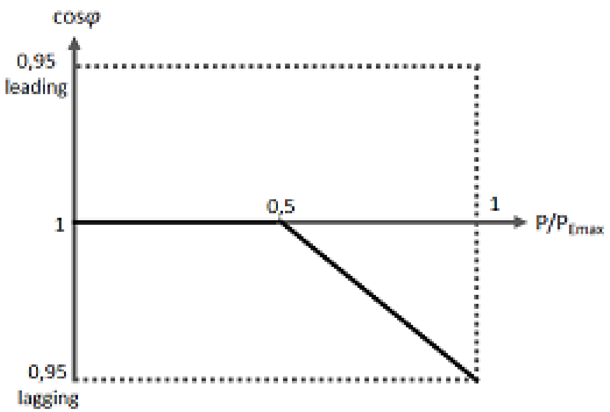
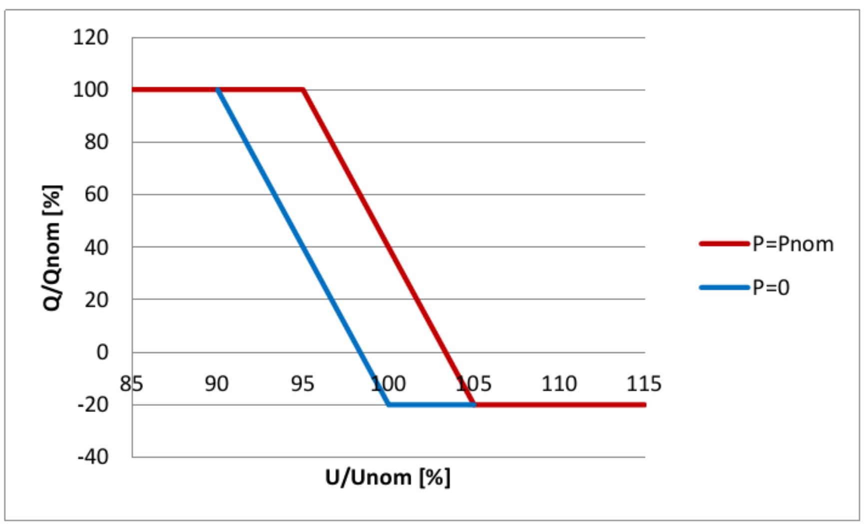


Figure 2 – default power factor

Reactive Power Control- 2/2

3. Q – a constant reactive power
   - Utilized in Germany
4. Q(U) – Q changes with grid voltage, according to a pre-defined graph.
   - Utilized in Slovenia, Italy, Germany
5. Q(U,P) – Q changes with P and with grid voltage, according to a pre-defined graph.
   - Utilized in Slovenia:



Israel Case Study

- High resistance and induction across the long linear grid lines going from north to south
- IEC demands that every medium voltage (22-33KV) PV system includes capacitors to:
  - Avoid grid voltage increase due to grid resistance
  - Mitigate phase lags due to grid induction
- Capacitors need to be controlled remotely by IEC to absorb grid reactive power on demand and manage Cosφ

Israel case study (cont.)

- Calculation of reactive power (Q) in an 850kW PV system, based on IEC's formula for a 33KV grid (example)
  - P_{PV} = 0.85MW
  - L = cable length from substation to PV installation = 70km

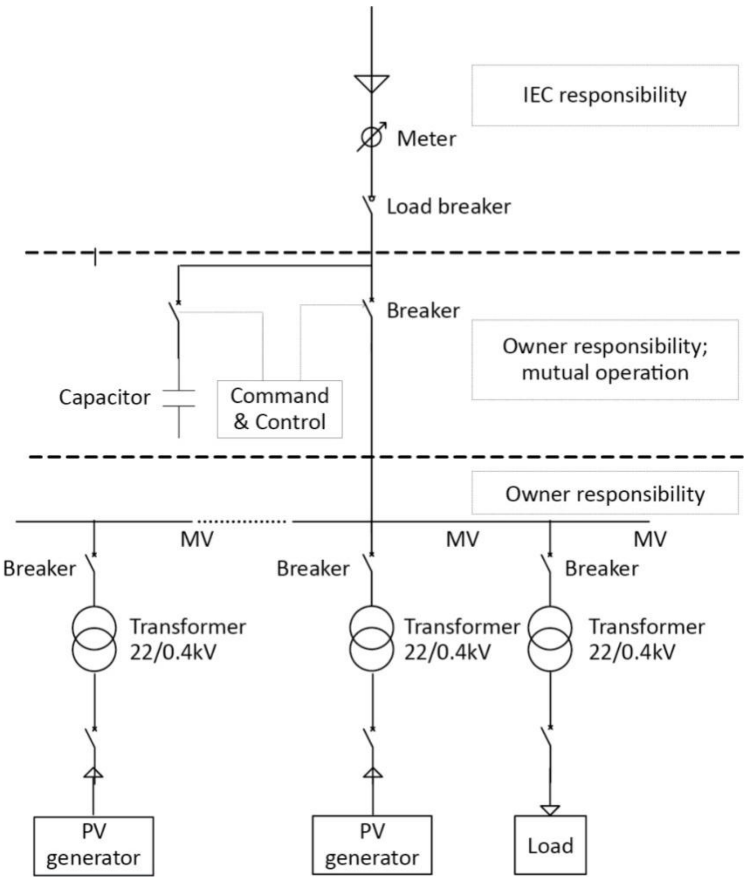
$$Q_{PV}\left[MVAR\right]\leq\frac{27.2-0.31\cdot L\cdot P_{PV}}{5.2+0.37\cdot L}$$

  - Q = 0.28MVAR

$P^2+Q^2=S^2$

Cosφ = P/S

  - Cosφ = 0.95



LVRT – Examples

Low Voltage Ride Through

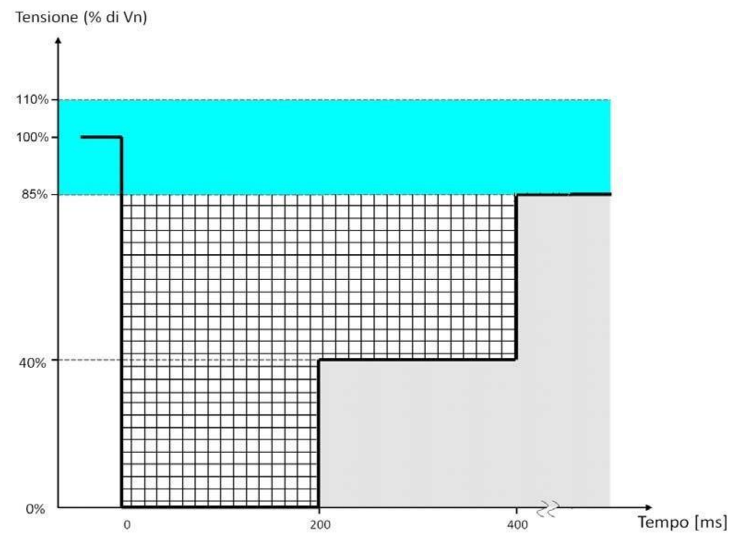
- Target: prevent immediate grid failure following grid instability
- Inverter must stay connected during a grid failure for a defined period of time (depending on voltage)
  - If voltage is back above limit – normal operation
  - Otherwise – inverter disconnection
- Utilized in Germany (MVGC only), Italy (systems >6kW), Japan

Example from Italian code:

Normal operation

Disconnection prohibited

Disconnection permitted



Inverter Design Implications

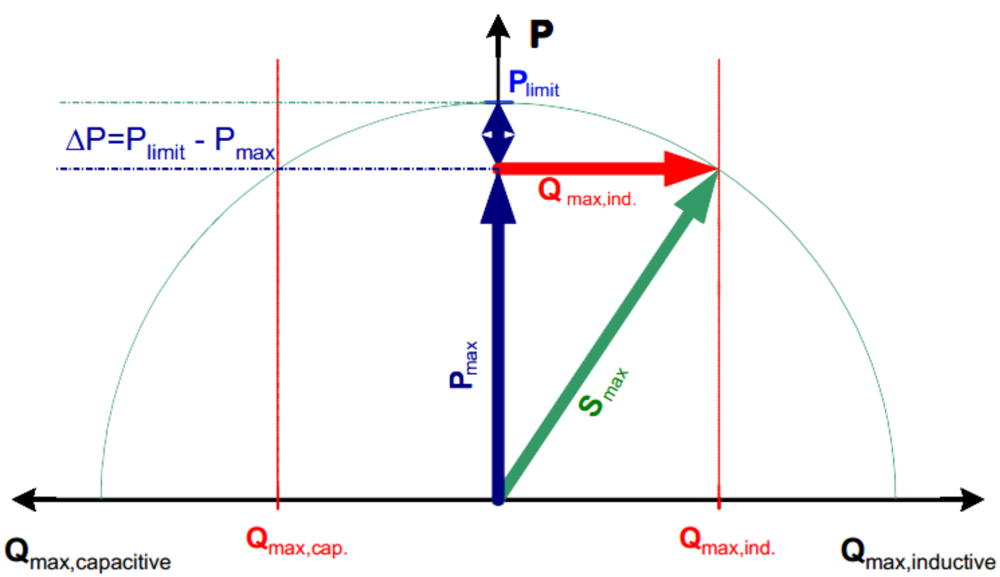
Inverter Design Implications

- Active and reactive power control:
  - Required firmware support
  - Where remote control is required, inverter must have interface to control device
  - Where gradual power reduction based on DC drop is required, inverter must have storage capability
- LVRT
  - Required firmware support
  - DC and AC side capacitors must be sized to store necessary capacitance and to withstand higher ripple during the period in which the inverter must not disconnect

Site Design Implications

System Design with Reactive Power Supply

- $P_{limit} = S$
- $\Delta P = P_{limit} - P_{max}$
- When Cosφ=1, $P_{max} = S$ and $\Delta P = 0$



Site Design Implications

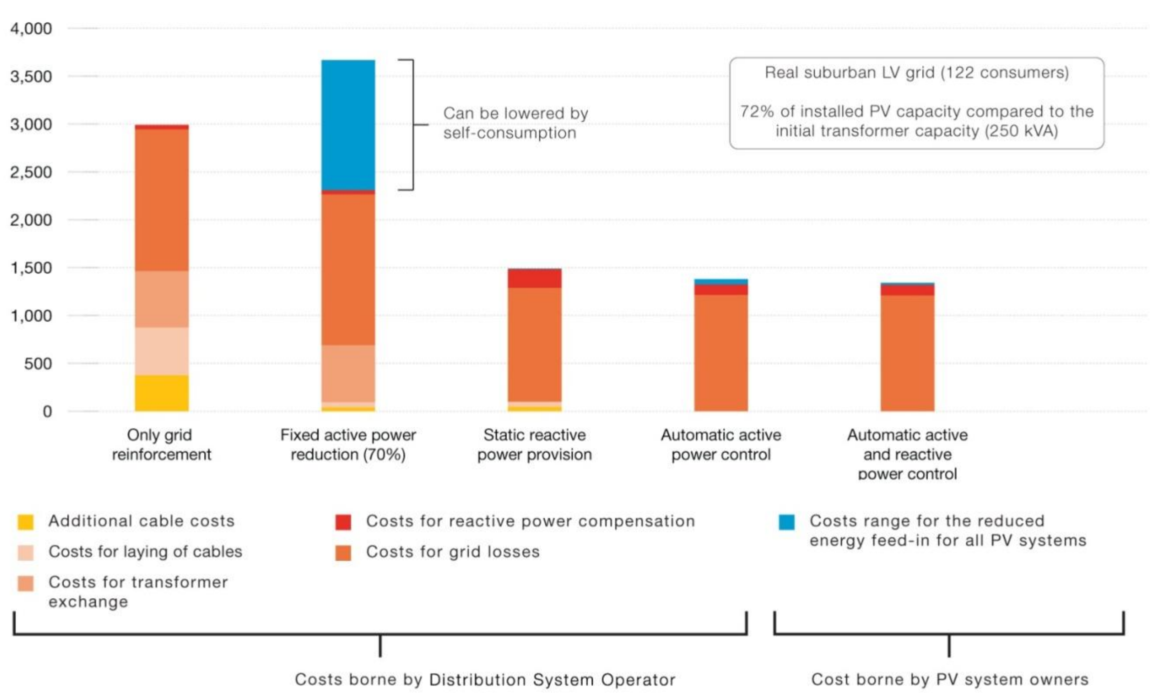
- Limitation of active or reactive power may affect system peak capacity or inverter selection
- Example: a system using the SE5000, an inverter with S=5kVA.
  - 110% DC/AC oversizing ratio is allowed -> up to 5.5kWp DC may be installed
    - If the inverter must be able to operate with Cosφ =0.95, then Pmax=0.95x5kVA=4.75kW
    - If the active power of the inverter is limited to 95%, Pmax=4.75kW
  - If a 110% DC/AC oversizing ratio is used, up to 5.2kWp DC may be installed.
  - If 5.5kWp DC is installed, a larger inverter needs to be used

Summary

Comparison of Grid Control Methods

- PV cost benefit analysis of different grid control strategies

€/year



source: Based on Fraunhofer IWES figures, 2012

SolarEdge Inverters

- Inverters specifically designed to work with power optimizers
- >98% maximum efficiency
- Simpler design → Highest reliability at minimal cost
- **All SolarEdge inverters support active power control, reactive power control and LVRT**

Single phase inverters 2.2kW – 6kW

Three phase inverters 5kW – 17kW

Commercial inverters 35kW – 50kW

Utility inverter 850kW

Thank you

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